Advanced High Efficiency Quick Start Fuel Processor for Transportation Applications

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Subcontractors/Partners:
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Engelhard Corporation
Worcester Polytechnic Institute
Calnetix

Objectives

With the STAR (Substrate-based Transportation Autothermal Reformer) and HiQ (High Efficiency Quick Start Transportation Fuel Processor) projects, Nuvera's goal is to develop an advanced fuel processing system for transportation applications. The HiQ concept combines a fuel processor, a fuel cell, and a turbogenerator for power generation and is also useful for stationary applications where high efficiency is critical. This is a combined report for both the STAR and HiQ projects.

STAR

- Develop technologies needed to improve the power density, specific power, and start-up time of fuel processors. These technologies include lightweight advanced low thermal mass catalysts, substrates, compact heat exchangers, and desulfurization media.
- Design and test the STAR fuel processor to ensure that it meets or exceeds FreedomCAR targets. Identify areas of improvement.
- Prove reliable operation of the fuel processor via integration with a proton exchange membrane (PEM) fuel cell.
- Increase system durability via fuel purification, reformate clean-up, catalyst advances, and mechanical design iterations.

HiQ

- Design, develop, and test a high power density, multi-fuel processor system that enables high efficiency and quick start operation of an integrated fuel cell power system for automotive applications. The concept will combine a low thermal mass catalytic fuel processor with a turbogenerator, leading to a hybrid system.
- Develop low-cost, high space velocity water-gas shift catalysts with subcontractors.
- Demonstrate rapid startup to low power and high net system efficiency.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- I. Fuel Processor Start-Up/Transient Operation
- J. Durability
- L. Hydrogen Purification/CO Clean-Up
- M. Fuel Processor System Integration And Efficiency
- N. Cost

Approach

STAR

- Perform automotive system analysis and identify strategies to meet FreedomCAR targets.
- Work closely with sub-contractors to develop key technologies and sub-components.
- Design, build, and test a compact integrated multi-fuel processor to investigate efficiency, power density, emissions, and reformate purity.
- Integrate the STAR fuel processor and a fuel cell, investigate the performance of the power system, and identify system level integration issues.
- Deliver the integrated fuel processing system to Argonne National Laboratory for testing.

HiQ

- Integrate STAR-type fuel processor with a turbo-generator system to recover waste energy from the fuel cell stack and provide capability for rapid start (less than one minute) to partial power levels.
- Design and build proof-of-concept fuel processor and turbo-generator system using conventional pelleted catalyst technologies.
- Demonstrate rapid start-up and high-efficiency operation on proof-of-concept system.
- Design and build high power density automotive multi-fuel fuel processor combining STAR and HiQ technologies.
- Deliver the integrated fuel processing system to Argonne National Laboratory for testing.

Accomplishments

STAR

- Continued to advance the compact fuel processor design using substrate-based catalysts, custom heat exchangers and burners, and innovative mechanical design.
- Fuel processor achieved automotive volume (75 liters), power density (2.1 kW-H_2/liter of fuel processor), and aspect ratio (<9 inch height).
- Tested the complete compact fuel processor on gasoline, ethanol, and natural gas.
- Achieved 200 kWth on gasoline with 80% hydrogen efficiency and CO < 50 ppm.
- Evaluated STAR operation on natural gas at 175 kWth feed rate with 74% hydrogen efficiency and CO < 50 ppm.
- Demonstrated STAR operation on ethanol at 180 kWth feed rate with 75% hydrogen efficiency and CO < 50 ppm.

- Integrated the fuel processor with a fuel cell to achieve 35 kWe and a gross efficiency of 31% (31 kWe from 100 kWth).
- Pushed the limits of the STAR design through durability testing and made significant advances in hours, thermal cycles, and mechanical design. The durability test results guided research into sub-component tests that are now ongoing.

HiQ

- Modeled, designed and constructed a proof-of-concept fuel processor system incorporating the key new technologies for the Nuvera HiQ combined-cycle process.
- Tested the HiQ proof-of-concept fuel processor in the laboratory with a stack simulator and a standard automotive turbocharger.
- Demonstrated less than 60 second start-up time to net power availability.
- Demonstrated fuel processor performance consistent with 40% net system efficiency.
- Demonstrated low exhaust emissions over entire start-up transient, as well as at steady state.
- Designed low cost integrated turbine-compressor-motor-generator system with sub-contractor and started development program.

Future Directions

STAR

- Complete testing on ethanol and natural gas.
- Continue fuel processor performance optimization on gasoline operation.
- Continue sub-component development with sub-contractors.
- Deliver fuel processor system to Argonne National Laboratory, complete STAR project, and submit final report.

HiQ

- Demonstrate proof-of-concept system over full load range.
- Demonstrate proof-of-concept system integrated with turbine-compressor-motor-generator subsystem.
- Design and build automotive fuel processor incorporating STAR technology advances.
- Demonstrate start-up, efficiency, and emissions characteristics of automotive fuel processor in conjunction with turbine-compressor-motor-generator.
- Deliver fuel processor with turbine-compressor-motor-generator to Argonne National Laboratory.

Introduction

Nuvera Fuel Cells, Inc. (Nuvera) is a leading developer and supplier of fuel cells, fuel processors, and integrated power systems for the stationary, industrial, and transportation markets. Nuvera is working with the U.S. Department of Energy (DOE) to develop efficient, low emission, on-board multi-fuel processors for the transportation application. The fuels of interest are gasoline, methanol, ethanol, and natural gas.

Approach

With the STAR and HiQ programs, Nuvera is addressing the goal of developing a high power density, quick start fuel processing system that also provides very high net direct current (DC) efficiencies when coupled with an appropriate fuel cell. The STAR project is focused on development of high power density substrate reforming technology, while the HiQ project to date has developed new system integration and power cycle technology to enable quick start and high efficiency. The STAR project will end in 2003; the HiQ project will continue by incorporating the STAR technology into a novel system integration scheme, capitalizing on the benefits of both.

Results

STAR. Based on catalyst, burner, and heat exchanger technologies produced in previous years, Nuvera built and tested several iterations of the compact STAR fuel processing system. The design, which has a total volume of ~75 L, contains all the catalytic reaction zones, the steam generation system, and heat exchangers (Figure 1). This fuel processor also has the shape factor necessary for installation in the fuel cell vehicle.

During this reporting period, Nuvera tested the STAR fuel processor on gasoline, ethanol, and natural gas. The design focus was gasoline, and the majority of the effort was spent on optimizing gasoline performance. The gasoline results exceeded targets, with a hydrogen efficiency of 80% and CO of less than 50 ppm at up to 200 kWth (Figure 2 shows 180 kWth data) feed rate. The STAR fuel processor also showed successful operation on ethanol and natural gas, processing both fuels with less than 50 ppm CO and hydrogen efficiencies of ~75%. Natural gas and ethanol testing focused on proving the fuel flexibility, and efficiencies were lower than gasoline only because time constraints prevented full optimization.

The STAR fuel processor also underwent durability testing to investigate the limits of the design. Mechanical durability has been improved significantly - over five enhancements in the longevity (hours) and 100% improvement in thermal cycle capability as compared to the previous compact fuel processors (Figure 3). The durability results suggested areas of sub-component research, which are currently underway both at Nuvera and sub-contractors.

To ensure high quality of STAR reformate, the fuel processor was integrated with a fuel cell (Figure 4). The integration was successful and produced 35 kWe and was limited only by the laboratory air supply system. The gross efficiency achieved was 31%, i.e. the system produced 31 kWe from the fuel cell with 100 kWth of gasoline fed to the fuel

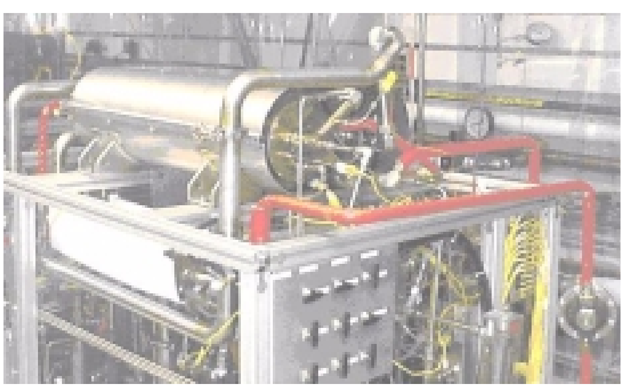

Figure 1. STAR Fuel Processor on Test Cart

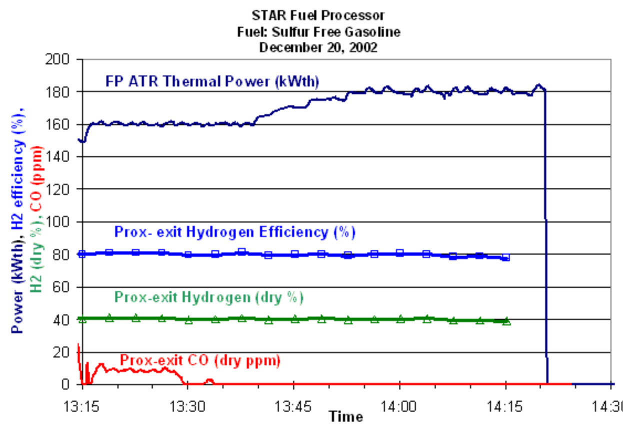

Figure 2. STAR Fuel Processor Operation on Gasoline (160-180 kWth)

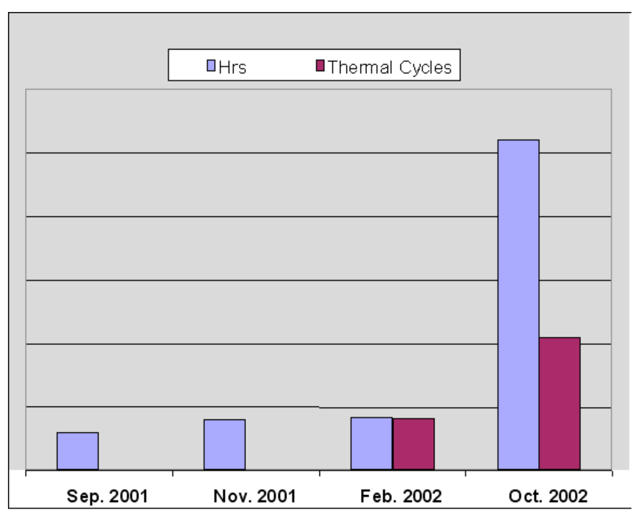

Figure 3. Durability Improvement of Nuvera STAR Fuel Processor

processor. There is significant room for improving the system efficiency; however, this is beyond the scope of the current project. The integration and fuel processor performance results indicate that the STAR fuel processor has the minimum rating of 62 kWe, exceeding the program target of 50 kWe.

The STAR fuel processor program represents a culmination of four years of intensive R&D and design efforts. Nuvera started with basic component testing of the catalysts and developed custom heat exchanger and burner designs. Today, Nuvera has combined these components to produce an advanced automotive fuel processor that finally achieves the volume, power, efficiency, hydrogen production, and reformate quality targets for onboard fuel processors.

HiQ. The focus of the HiQ project in the past year has been on proving the feasibility of increasing system efficiency and decreasing startup time via novel system integration strategy. The block diagram shown in Figure 5 outlines the HiQ system configuration. High system efficiency is achieved by using the waste heat from the stack to evaporate water into the cathode air. The resulting flow of water vapor is heated to an appropriate temperature in the combustor and passed through the turbine, where it generates mechanical power. The integrated generator on the turbine shaft converts this mechanical power into electrical output. Thus, the system converts heat that is ordinarily wasted into useful electrical power, which improves the overall system efficiency.

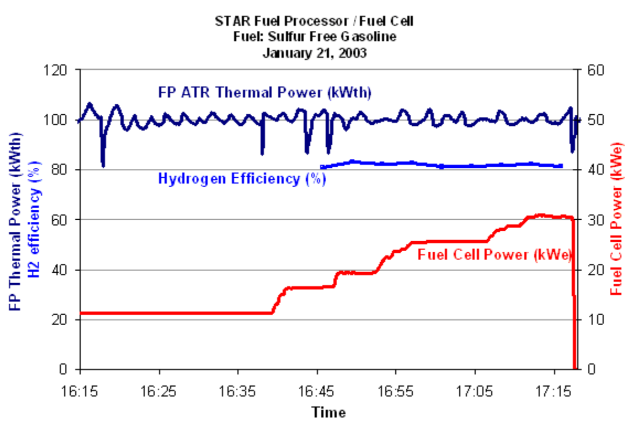

Figure 4. STAR Fuel Processor/Fuel Cell Integration

The technical challenges involved include combustor, heat exchanger, and fuel processing improvements to enable this heat-to-power conversion to take place. A key aspect of the process is that the combustor technology developed by Nuvera in this project allows the use of high-temperature automotive turbine technology. Not only does this reduce cost, but it also allows quick start-up; the combustor and turbo-generator can be operated as a micro-turbine at start-up, allowing for some power production even before the fuel processor is warmed up and the fuel cell is producing power.

The feasibility demonstration was successfully carried out using a proof-of-concept fuel processor, stack simulator, and automotive turbocharger.

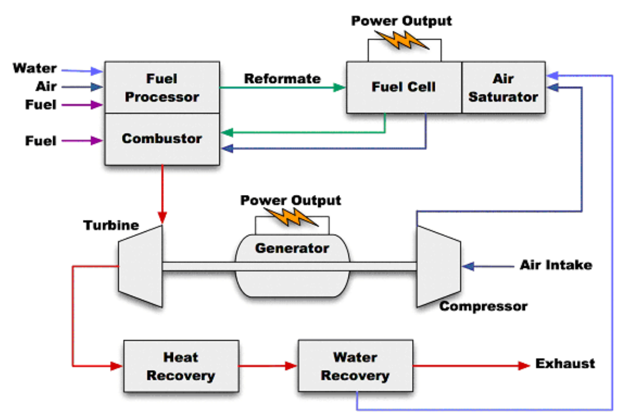

Figure 5. HiQ System Integration Concept

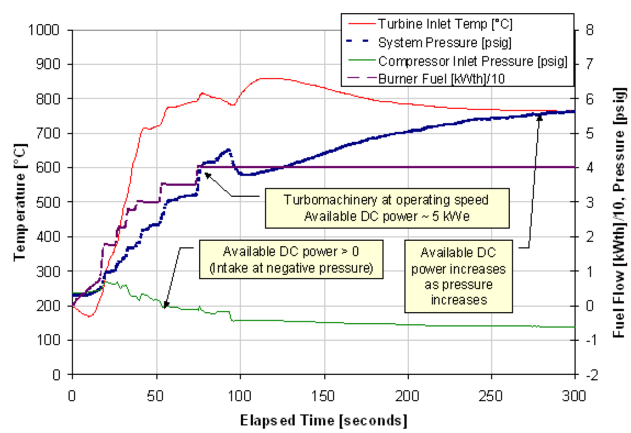

Figure 6. Plot of HiQ system startup with automotive turbocharger used as placeholder for turbine/compressor/motor/generator system. The system reaches a state that will correspond to net power output from the turbo-generator in less than 60 seconds from start-up.

Computational models were used to project fuel cell and turbo-generator power output levels based on the observed laboratory data. As shown in Figure 6, the start-up time to the low power micro-turbine mode has been demonstrated to be less than 60 seconds.

Conclusions

STAR

- The substrate-based STAR fuel processor meets the volume (75 L), power (200 kWth), hydrogen efficiency (80%), and CO (<50 ppm) targets for onboard fuel processors.
- Durability testing of the STAR fuel processor showed great improvements in mechanical design and suggested areas of research that are currently ongoing.
- A STAR fuel cell/fuel processor integration proved high reformate quality with successful operation of the fuel cell.

HiQ

- A proof-of-concept fuel processor system has been developed and has demonstrated the feasibility of the HiQ system integration scheme.
- Laboratory results support projections of start-up times of less than 60 seconds to partial power levels.

FY 2003 Publications/Presentations

1. Jian L. Zhao, William Northrop, Timothy Bosco, Brian Bowers, *On-Board Gasoline Fuel Processor ---- STAR.* AIChE 2003 Spring National Meeting – Topical Conference on Fuel Cell Technology, Session 99, New Orleans, LA, 30 March-3 April 2003.

2. Lawrence Clawson, James Cross, Christopher O'Brien, *Development and Analysis of a 50 –100 kW Hybrid Cycle Integrated PEM Fuel Cell and Fuel Processor System with High Efficiency and Rapid Start-up*, presented at "Fuel Cell Advances 2002," Amsterdam, The Netherlands, 25-26 September 2002.